



US009217631B2

(12) **United States Patent**  
**Meinherz et al.**

(10) **Patent No.:** **US 9,217,631 B2**  
(45) **Date of Patent:** **Dec. 22, 2015**

(54) **INTEGRATED LASER ALIGNMENT AID  
USING MULTIPLE LASER SPOTS OUT OF  
ONE SINGLE LASER**

(71) Applicant: **CEDES SAFETY & AUTOMATION  
AG, Landquart (CH)**

(72) Inventors: **Carl Meinherz, Malans (CH); Richard  
Casty, Chur (CH)**

(73) Assignee: **CEDES SAFETY & AUTOMATION  
AG, Landquart (CH)**

(\*) Notice: Subject to any disclaimer, the term of this  
patent is extended or adjusted under 35  
U.S.C. 154(b) by 61 days.

(21) Appl. No.: **13/902,238**

(22) Filed: **May 24, 2013**

(65) **Prior Publication Data**

US 2013/0258337 A1 Oct. 3, 2013

**Related U.S. Application Data**

(63) Continuation-in-part of application No. 13/757,321,  
filed on Feb. 1, 2013.

(51) **Int. Cl.**

**G01B 11/14** (2006.01)

**F16P 3/14** (2006.01)

**G01V 8/20** (2006.01)

**G01B 11/27** (2006.01)

**G02B 27/10** (2006.01)

**G02B 27/12** (2006.01)

(52) **U.S. Cl.**

CPC ..... **G01B 11/14** (2013.01); **F16P 3/144**  
(2013.01); **G01B 11/27** (2013.01); **G01V 8/20**  
(2013.01); **G02B 27/106** (2013.01); **G02B**  
**27/1093** (2013.01); **G02B 27/126** (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

(56) **References Cited**

**U.S. PATENT DOCUMENTS**

2,485,377	A *	10/1949	Griffin	362/294
3,060,310	A *	10/1962	Bertsche, Jr. et al.	362/221
3,100,847	A *	8/1963	Von Hacht	250/237 R
5,302,942	A	4/1994	Blau	
6,124,586	A *	9/2000	De Coi	250/221
7,508,512	B1 *	3/2009	Rollins et al.	356/399
2002/0017604	A1 *	2/2002	Nakazaki et al.	250/221
2004/0042010	A1 *	3/2004	Wuestefeld	356/400
2005/0207724	A1	9/2005	Boeckel et al.	
2010/0127158	A1	5/2010	Scheiber et al.	
2010/0219326	A1 *	9/2010	Klein et al.	250/201.1
2011/0204211	A1 *	8/2011	Klingelhofer	250/208.2

**FOREIGN PATENT DOCUMENTS**

CN	200949744	Y *	9/2007
DE	20304211	U1 *	6/2003
DE	102009021645	B3 *	11/2010
DE	202011051295	U1	12/2011
EP	0964273	A2	12/1999
EP	2511737	A1	10/2012
GB	2364773	A	2/2002
JP	2010310	A	1/1990
WO	2011114571	A1	9/2011

\* cited by examiner

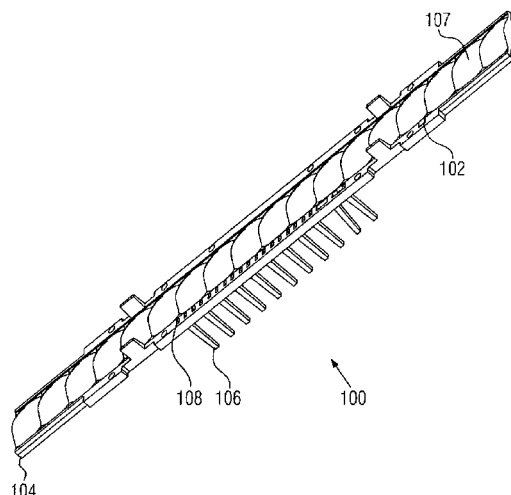
*Primary Examiner* — Gordon J Stock, Jr.

(74) *Attorney, Agent, or Firm* — Boyle Fredrickson, S.C.

(57) **ABSTRACT**

The present invention relates to light curtains, in particular safety light curtains, for monitoring a protective field. Furthermore, the present invention relates to optical units which are part of such a light curtain. An optical unit for an alignment system of a light curtain monitoring a protective field comprises an optical processing element for generating a defined radiation pattern from the radiation emitted by an alignment radiation source, and at least one additional optical functional element being formed integrally with the optical processing element.

**16 Claims, 18 Drawing Sheets**



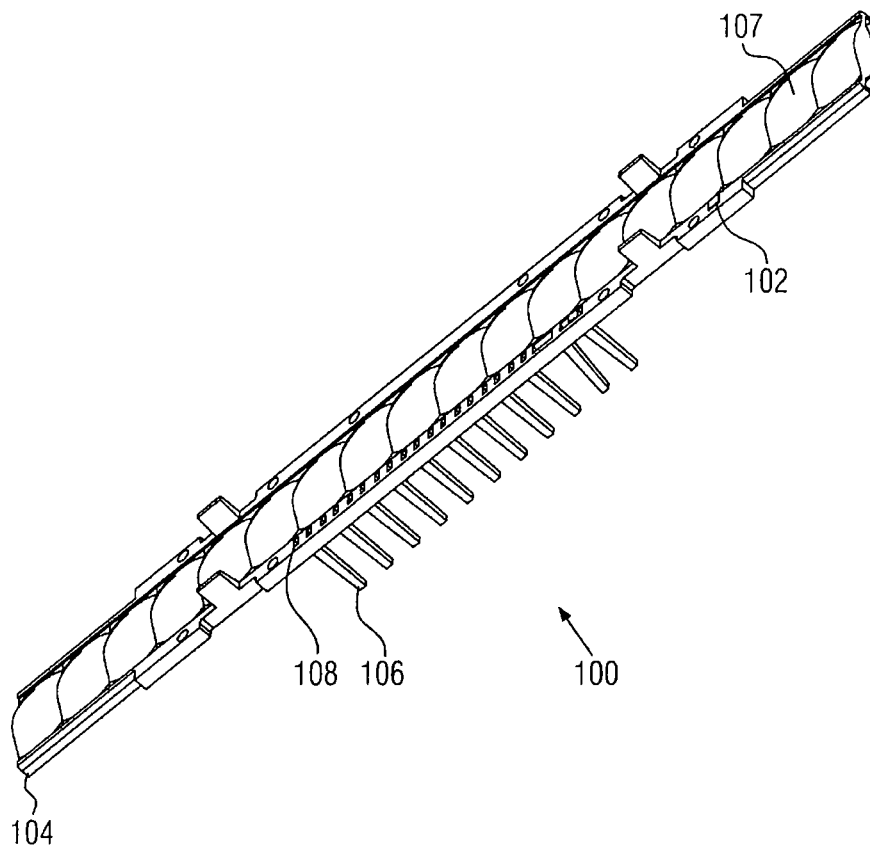
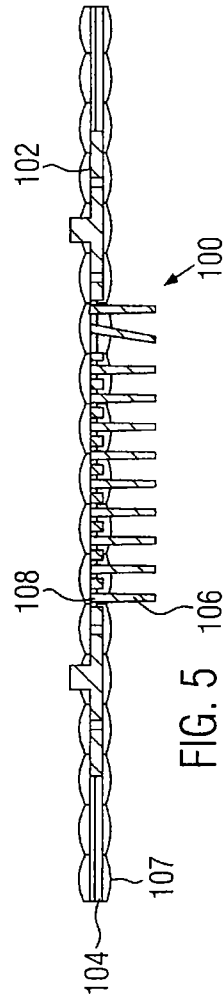
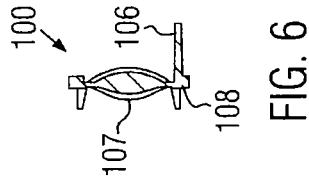
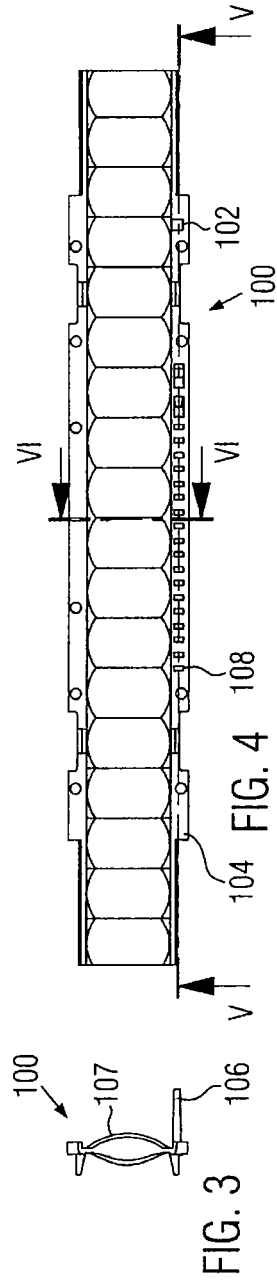
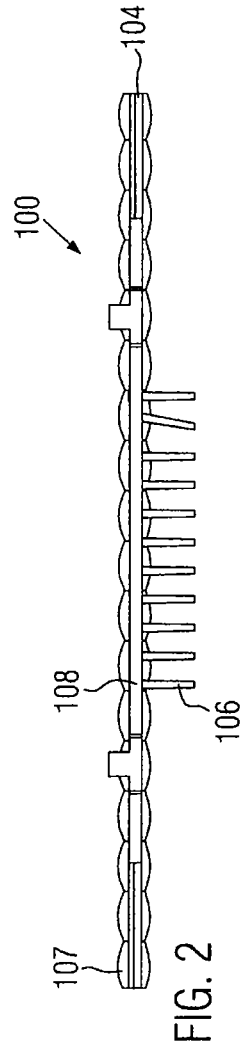


FIG. 1



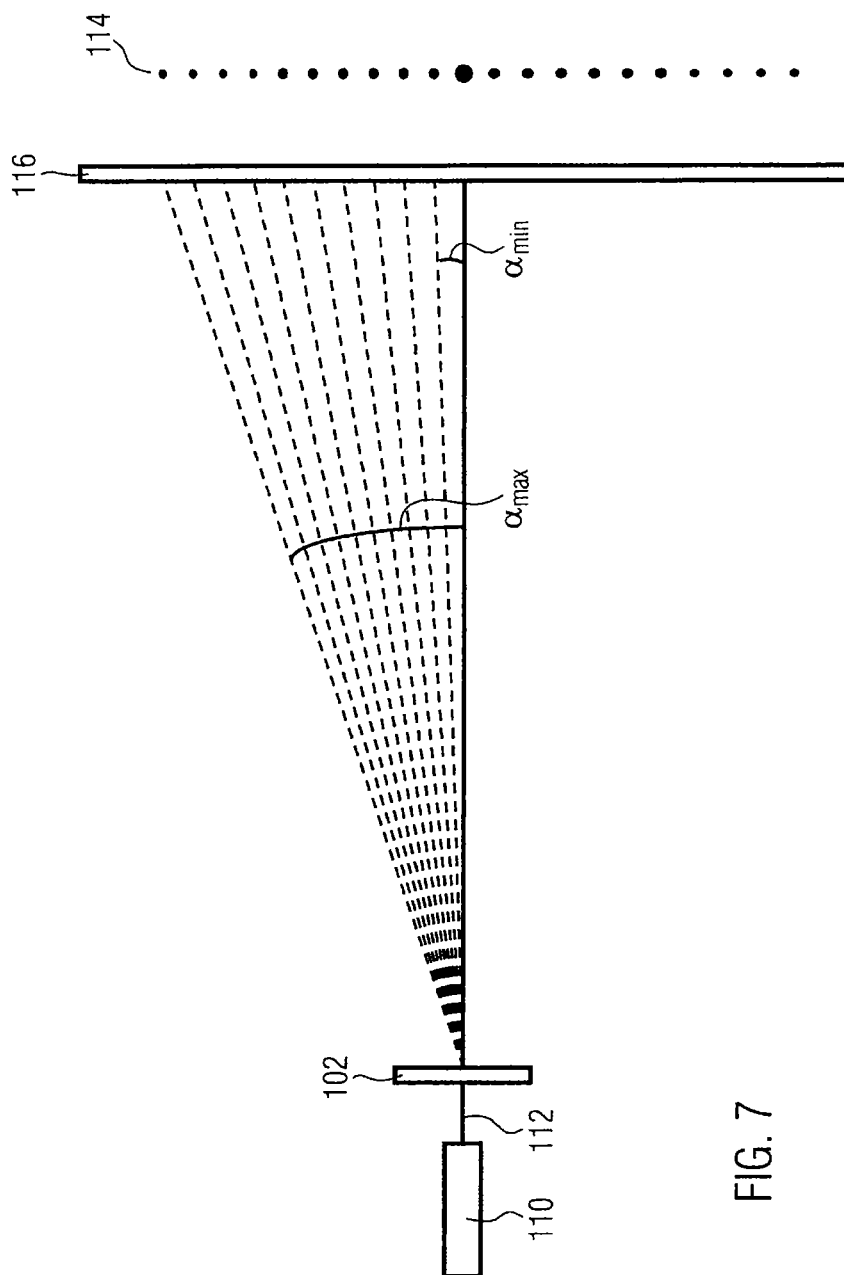


FIG. 7

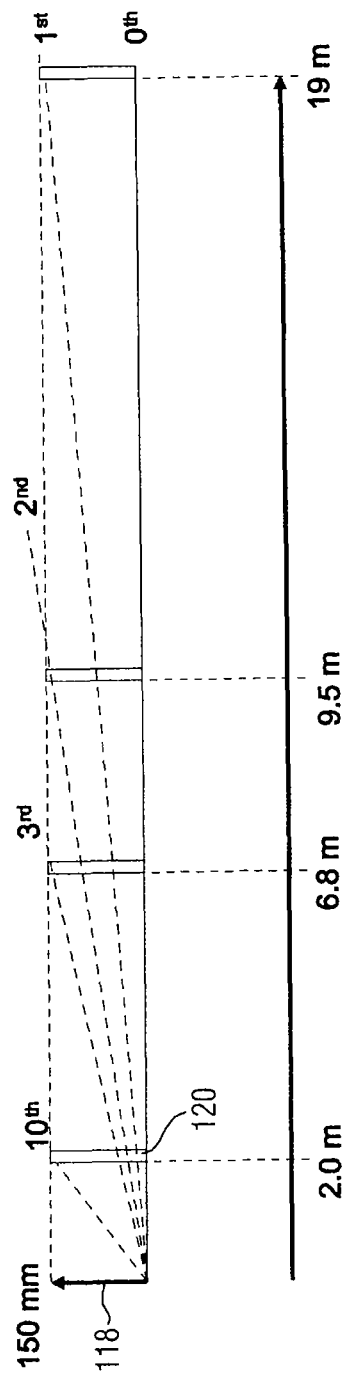


FIG. 8

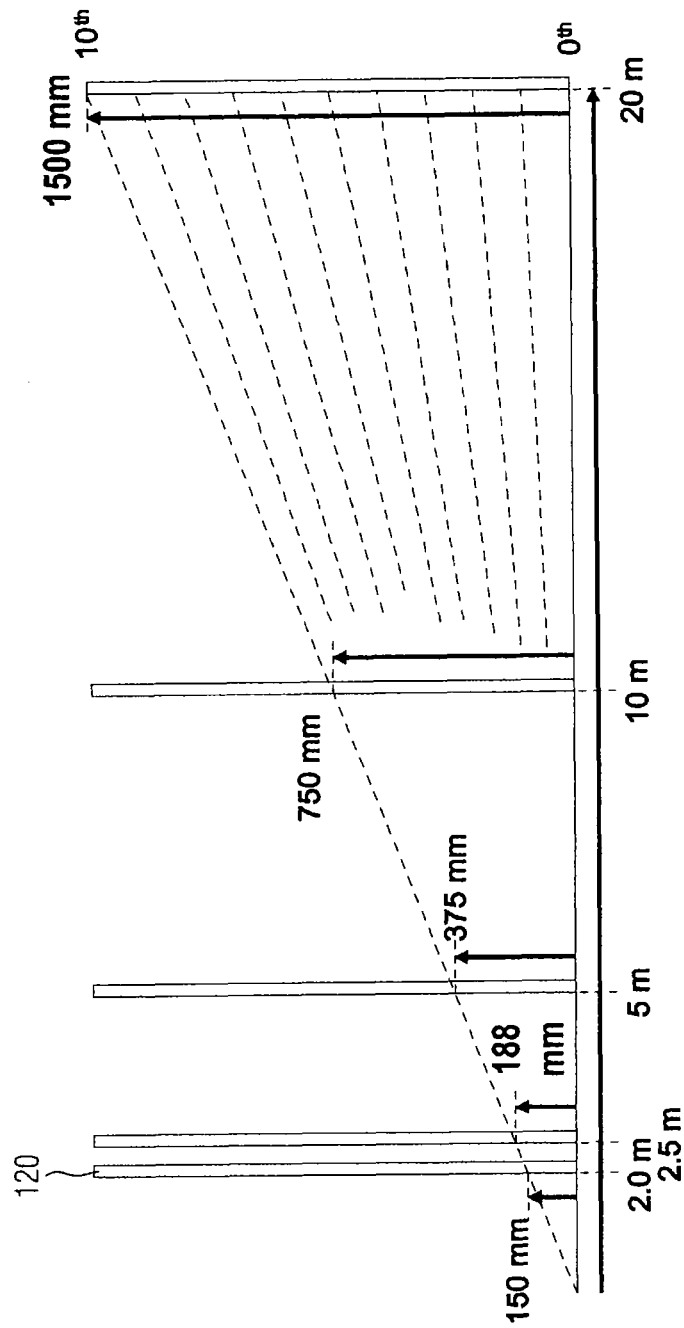


FIG. 9

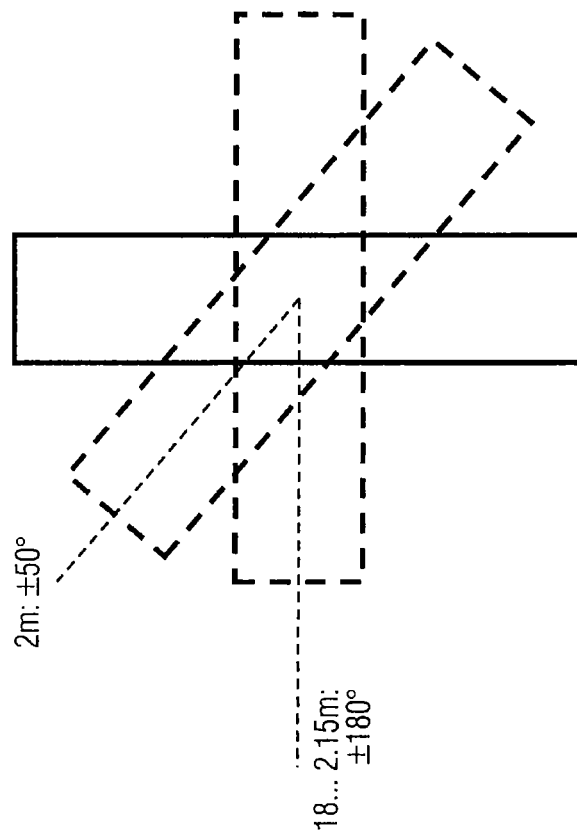


FIG. 10

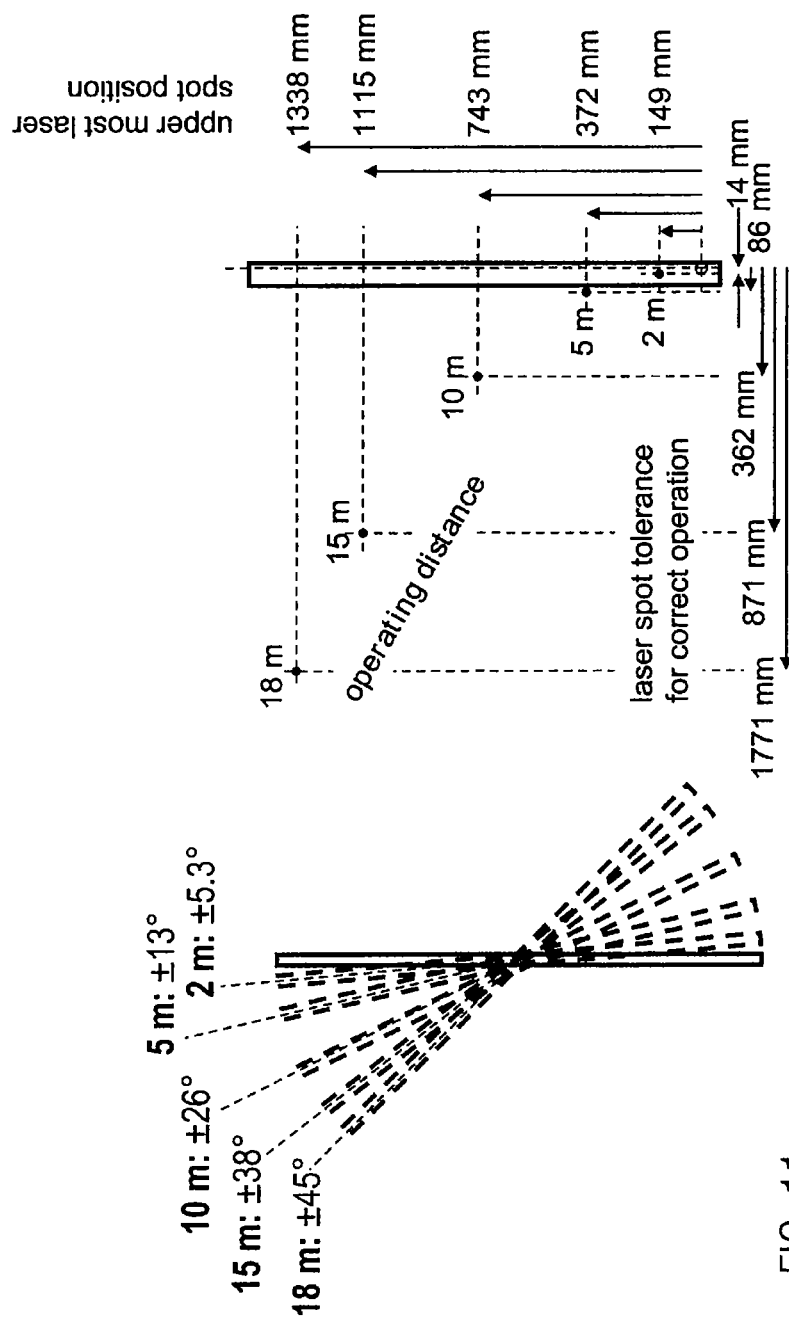


FIG. 11

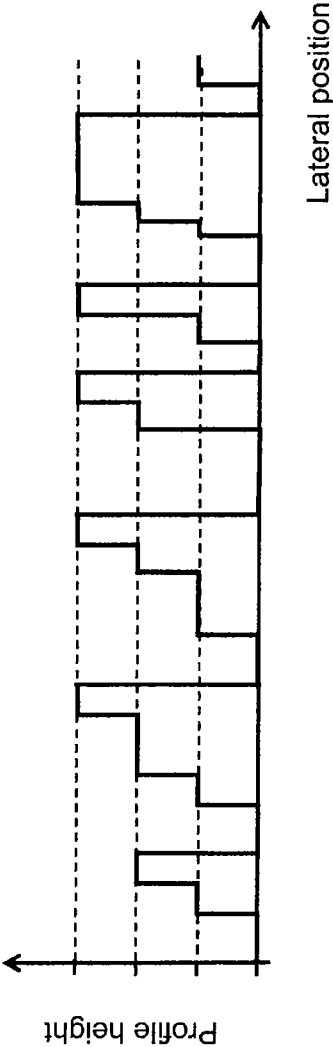


FIG. 12

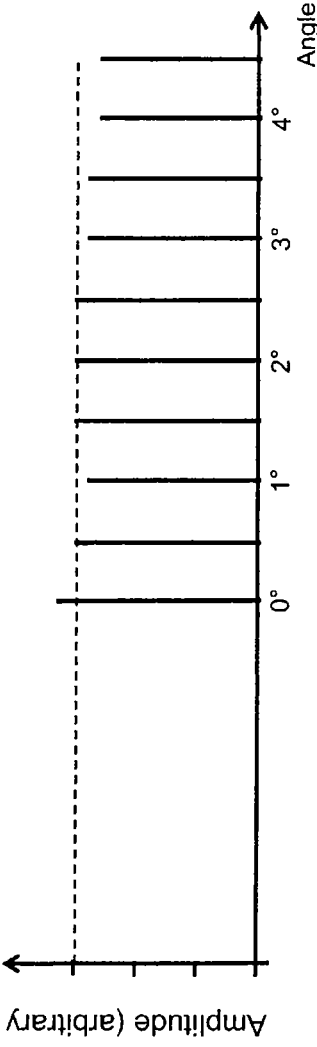


FIG. 13

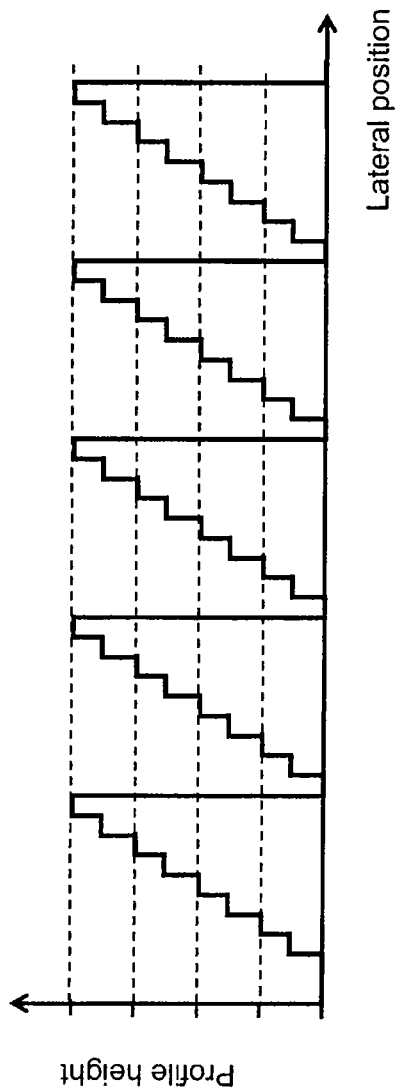


FIG. 14

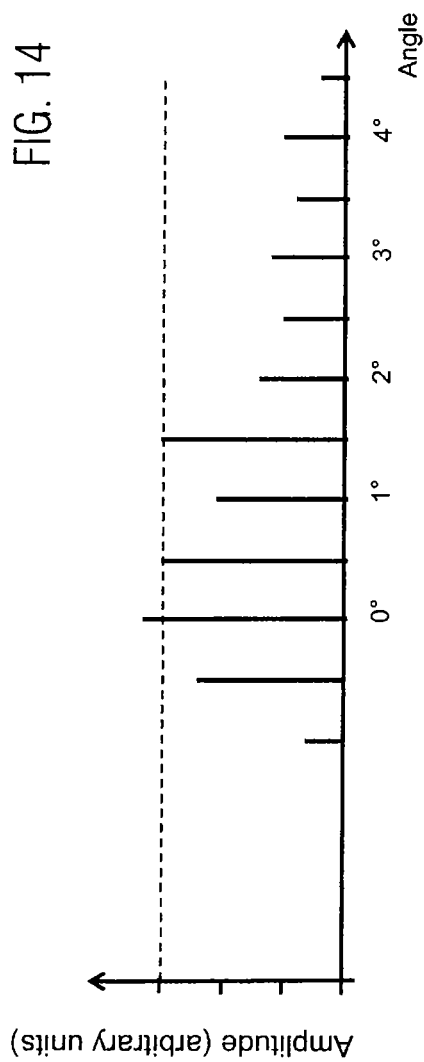


FIG. 15

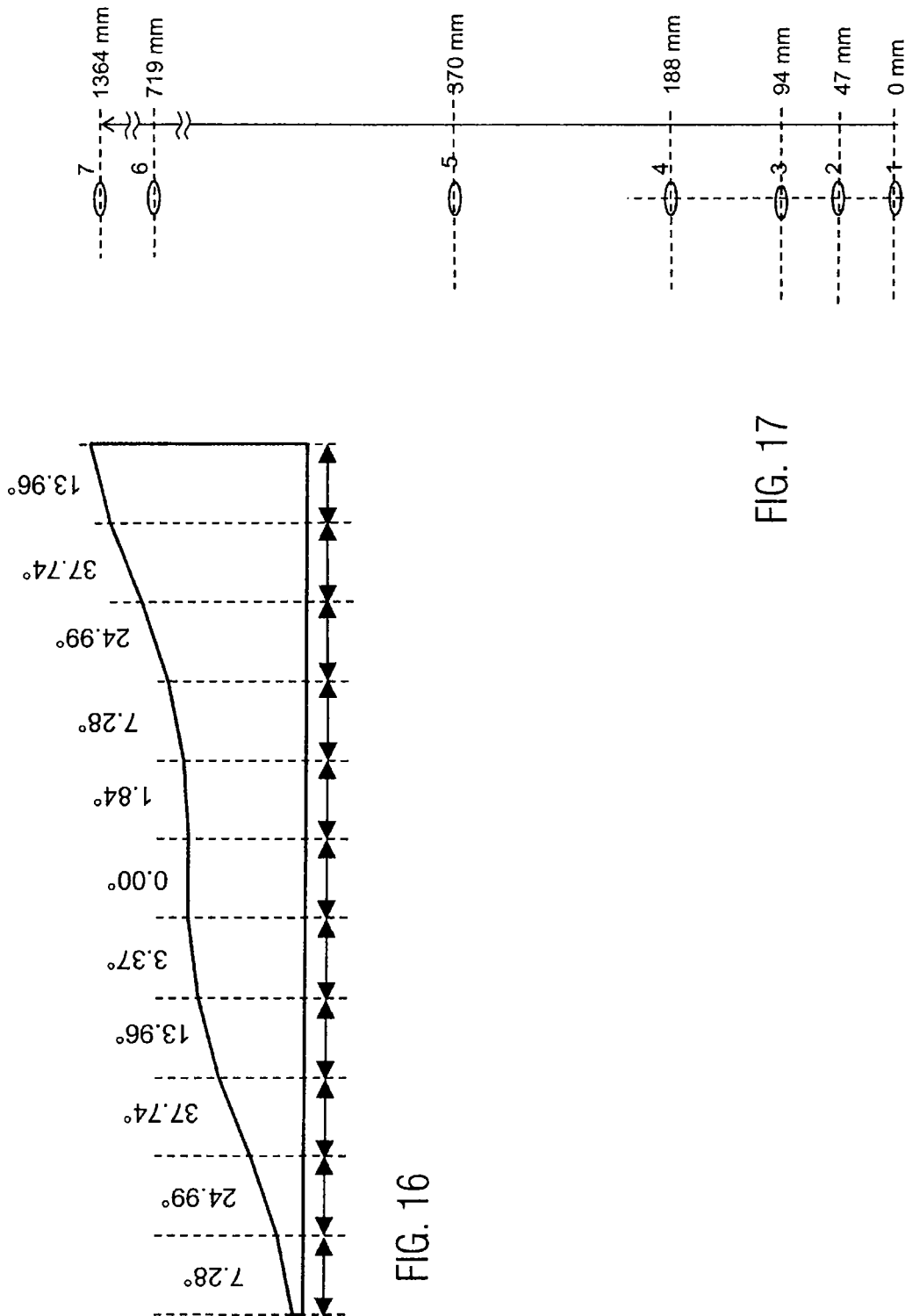
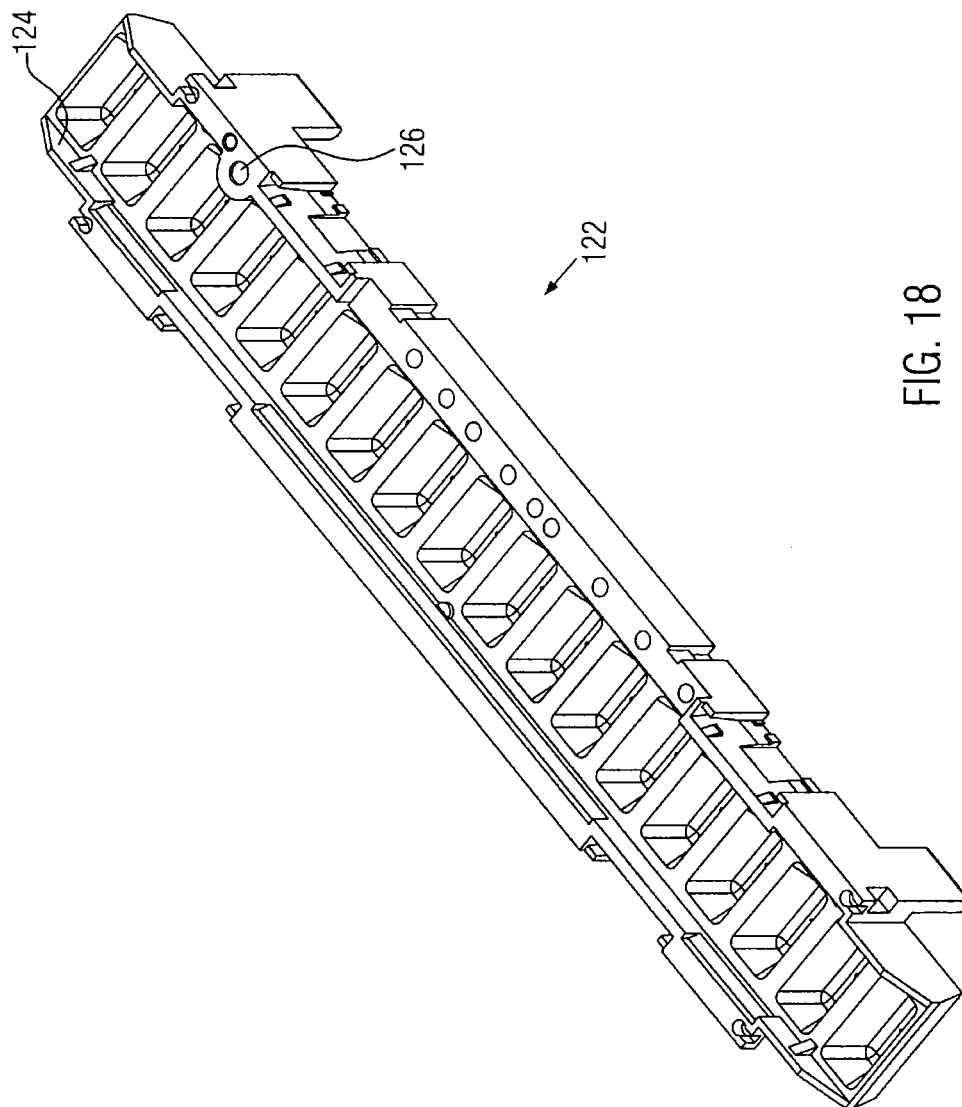
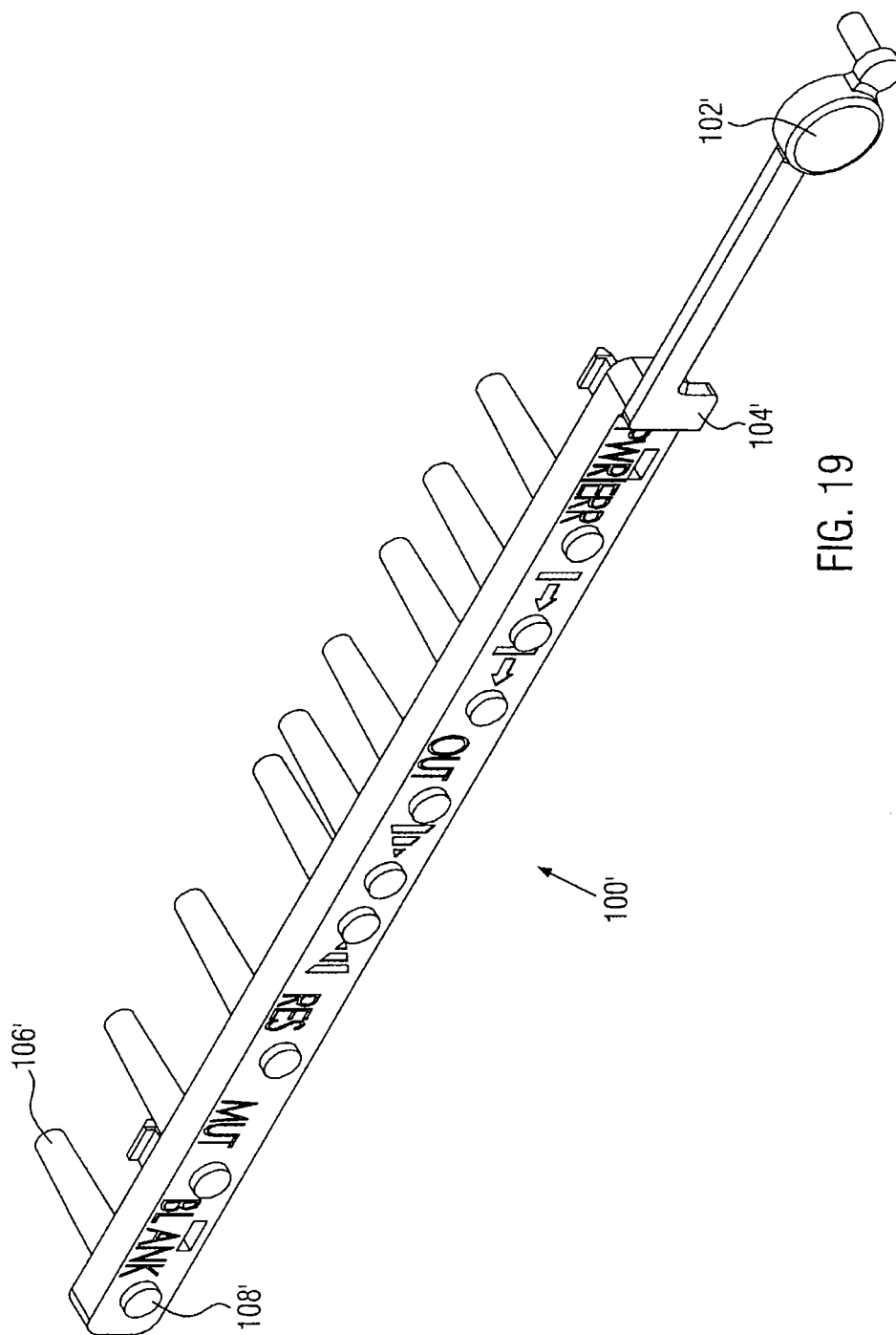


FIG. 17

FIG. 16





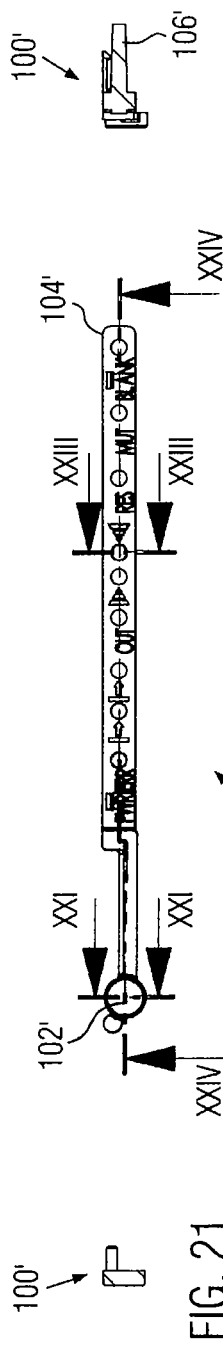
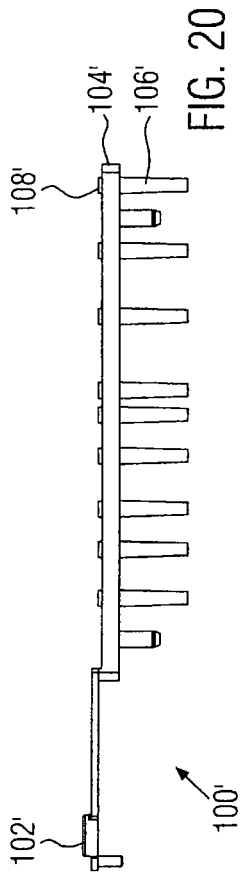


FIG. 23

FIG. 22

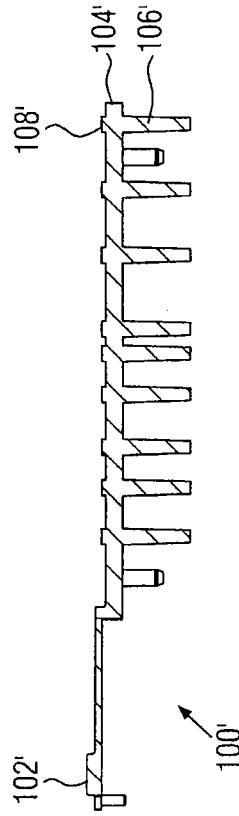
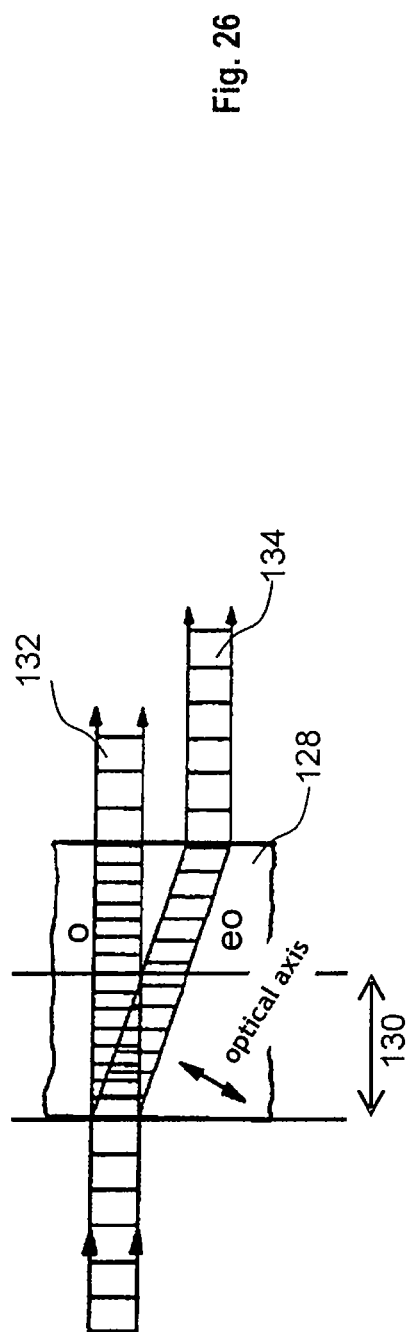
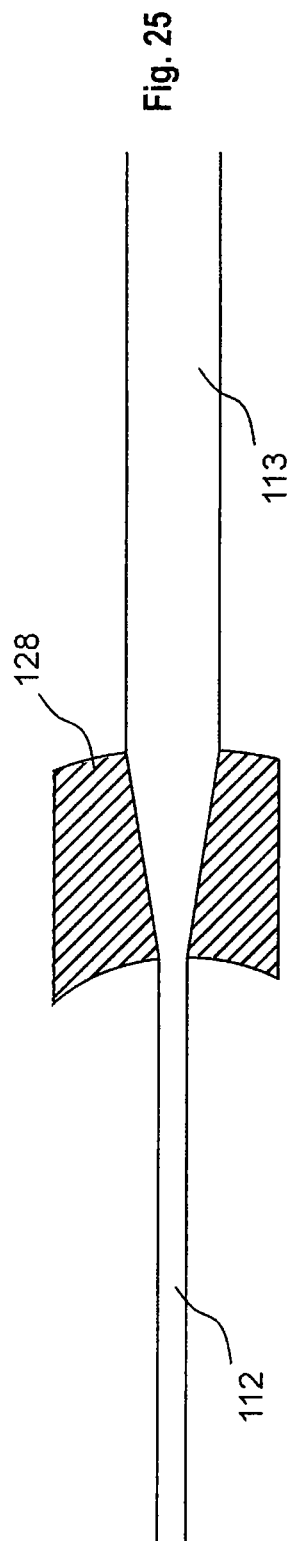


FIG. 24



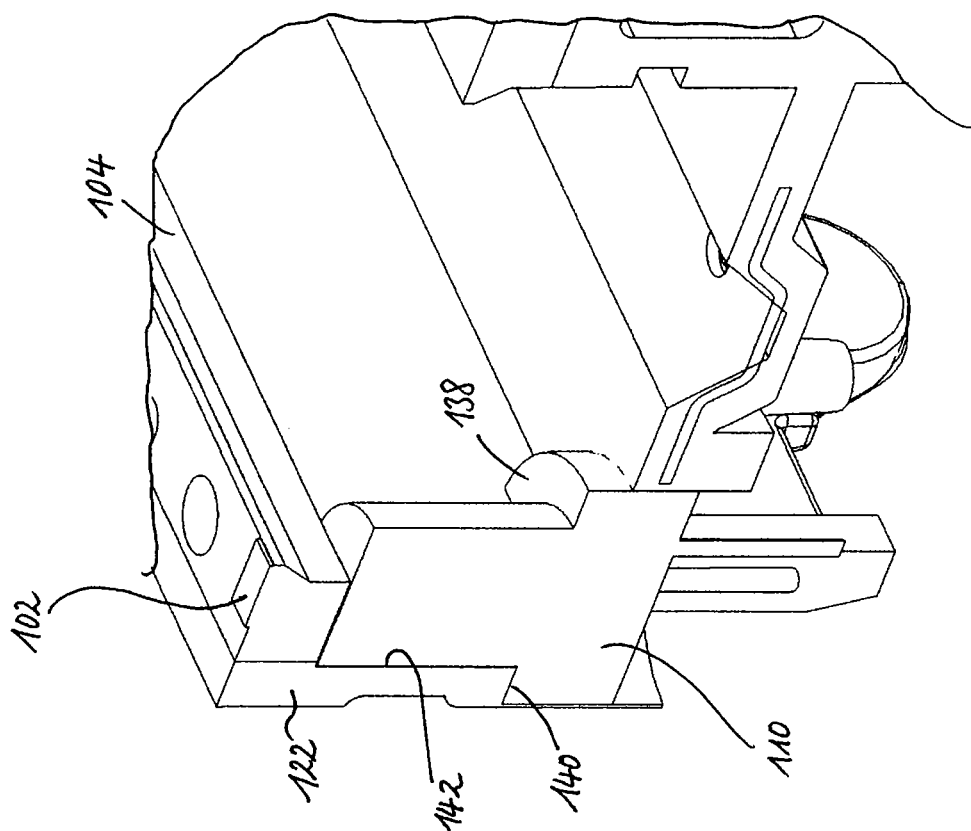


Fig. 28

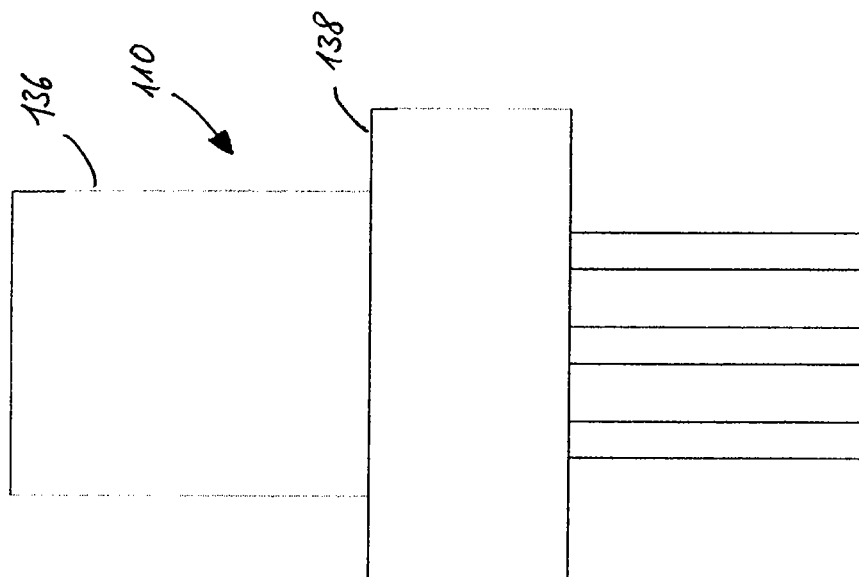


Fig. 27

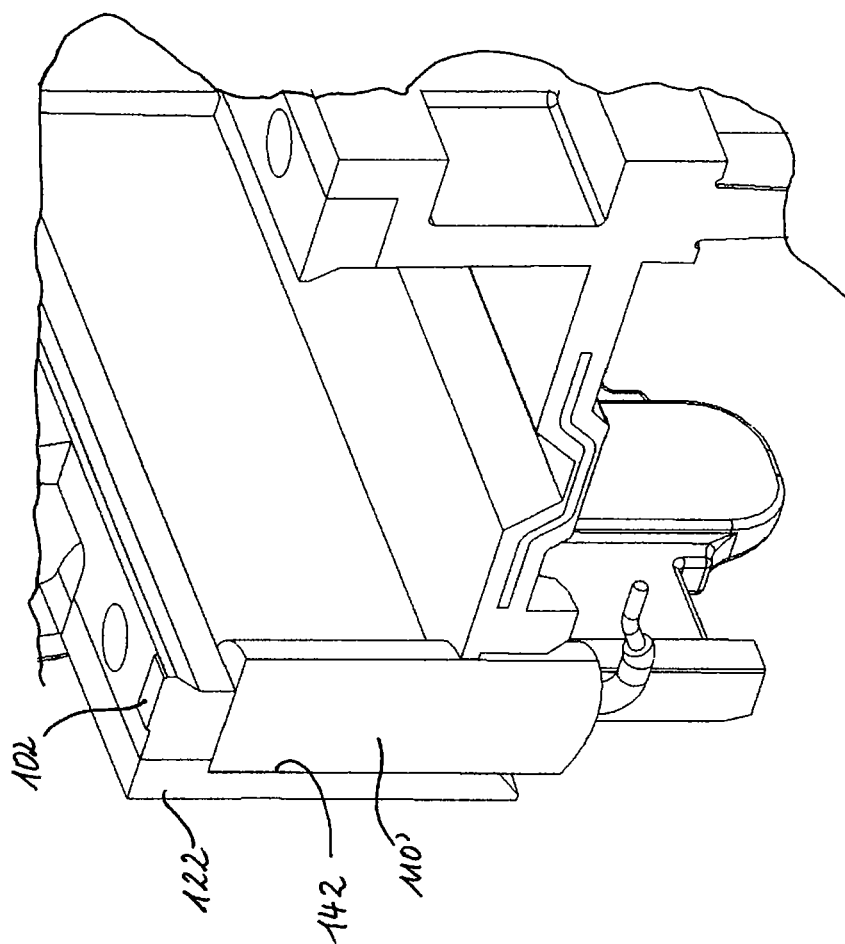


Fig. 30

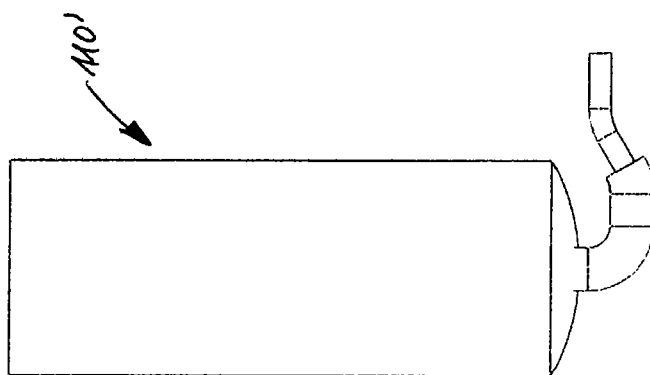


Fig. 29

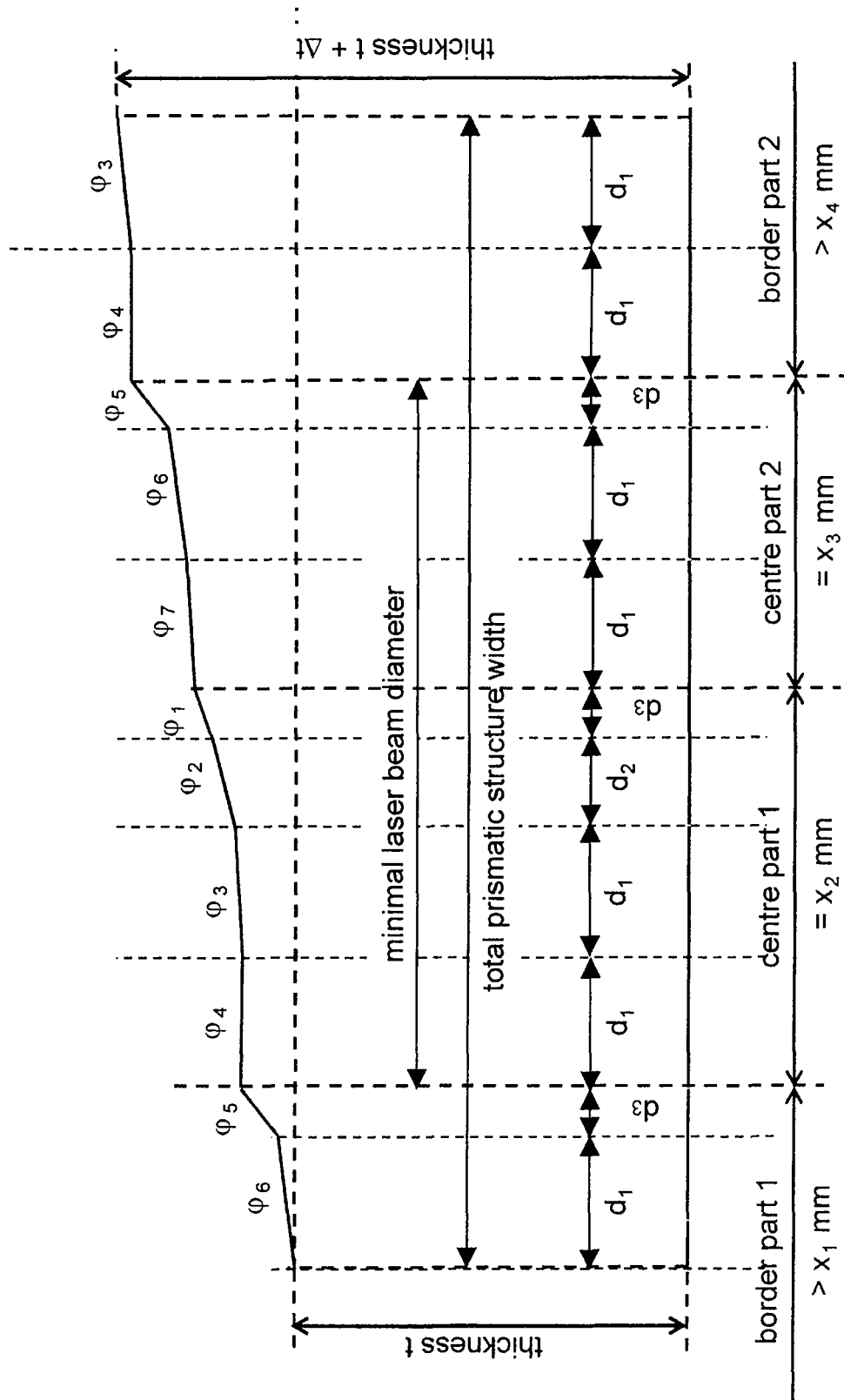


Fig. 31

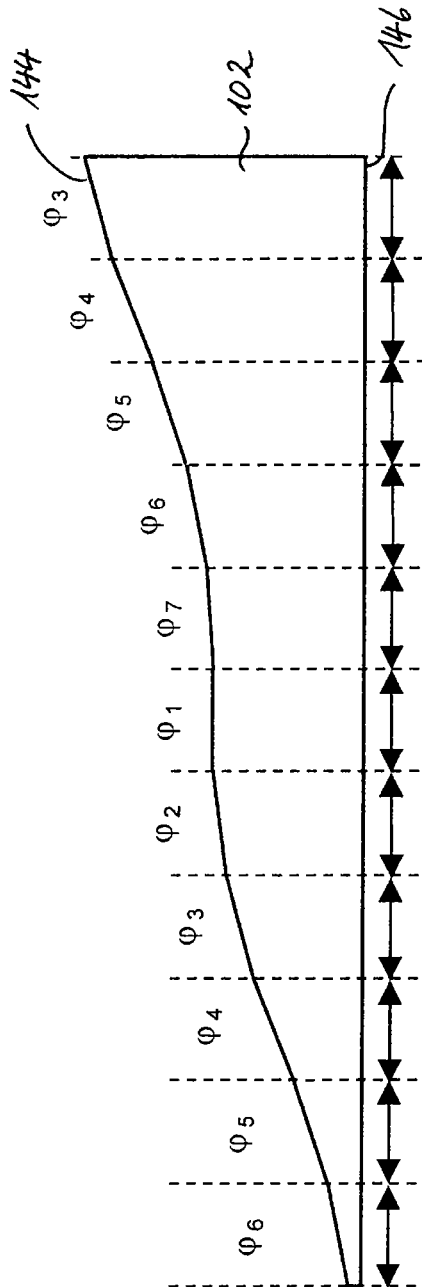


Fig. 32

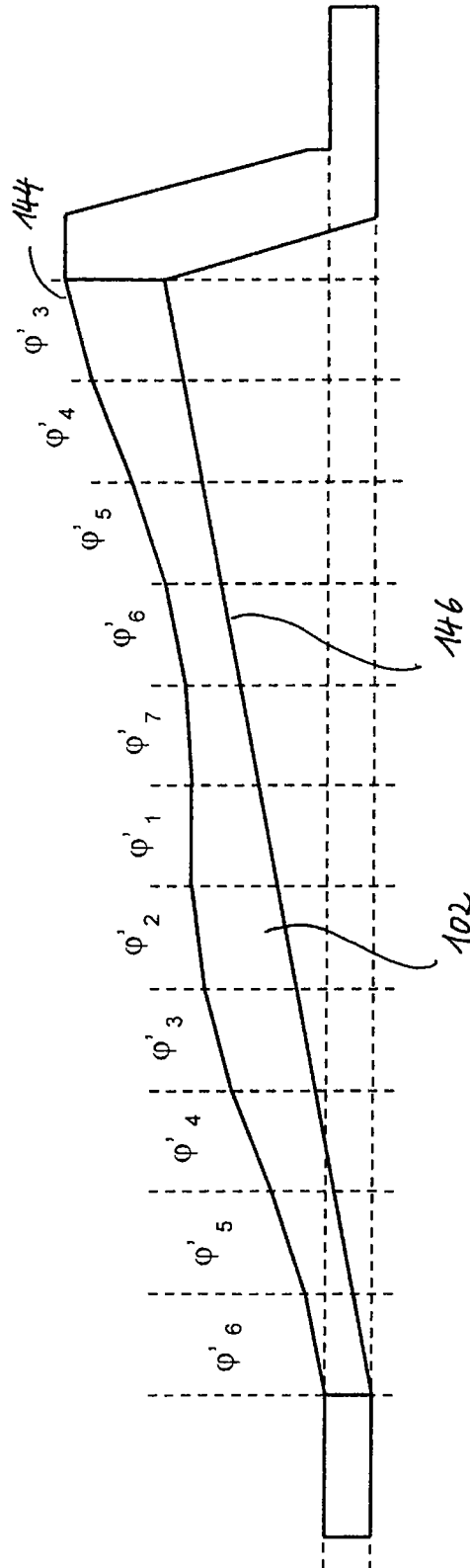


Fig. 33

# INTEGRATED LASER ALIGNMENT AID USING MULTIPLE LASER SPOTS OUT OF ONE SINGLE LASER

## CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of U.S. application Ser. No. 13/757,321 filed on Feb. 1, 2013, which claims priority to European Application No. EP12153555 filed on Feb. 2, 2012, the disclosures of which are expressly incorporated herein.

## BACKGROUND OF THE INVENTION

The present invention relates to light curtains, in particular, safety light curtains for monitoring a protective field. Furthermore, the present invention relates to optical units which are part of such a light curtain.

Generally, light curtains detect the movement or intrusion of objects into guarded zones, and more particularly, provide protection for human operators who are working with machines or other industrial equipment.

Light curtains employing infrared or visible light beams are used to provide operator safety in a variety of industrial applications. Light curtains typically are employed for operator protection around machinery, such as punch presses, brakes, molding machines, automatic assembly equipment, coil winding machinery, robot operation, casting operations and the like. Conventional light curtains typically employ light emitting diodes (LED) mounted at spaced positions along a transmitter bar at one side of the guard zone and phototransistors (PT), photodiodes or photoreceivers mounted along a receiver bar at the opposite side of the zone. The LEDs transmit modulated infrared light beams along separate parallel channels to the PTs at the receiver bar. If one or more beams are blocked from penetration by an opaque object, such as the operator's arm, a control circuit shuts the machine down, prevents the machine from cycling, or otherwise safeguards the area.

Usually, safety light curtains comprise two optical units (called bars, sticks, or strips), which are formed as two different constructional units, one of the optical units having the functionality of an emitter and one of a receiver. This dedicated architecture of an emitter and receiver, however, has several drawbacks, for instance the fact that the fabrication costs are high, because each type of optical unit has to be fabricated differently. Consequently, there exist concepts that use an architecture wherein each optical unit has a transceiver unit carrying a plurality of light emitting elements and light receiving elements and at least one separate detachable plug-in module. The first and second transceiver units are identically built, whereas the first and second plug-in modules differ from each other and thus define the functionality of the respective optical unit. For instance, the plug-in module differentiates an optical unit as the emitter with, for instance, the test input, or as the receiver with, for instance, the output signal switching devices, OSSD.

Such a modular architecture is for instance proposed in the European patent application EP 11162263.5 and allows a very cost-effective fabrication, because the transceiver modules are identically built and, furthermore, can be applied in a very flexible way for a multitude of applications and system configurations.

However, this modular transceiver bar configuration is not compatible with laser alignment techniques that employ one laser module as a radiation emitter at each stick, but at differ-

ent locations for the dedicated receiver and transmitter bar, respectively, as this is for instance shown in the published European patent EP 0889332 B1.

In order to provide an alignment system for systems based on transceiver bars according to the European patent application EP 11162263.5, one possible solution could therefore be seen in providing two laser modules for each transceiver bar. This concept, however, increases the costs due to the additional laser emitter for each transceiver bar.

The object underlying the present invention is to provide a light curtain and an optical unit for a light curtain, which can be fabricated in a particularly cost-effective way, and allow for an accurate alignment and synchronization.

This object is solved by the subject matter of the independent claims. Advantageous embodiments of the present invention are the subject matter of the dependent claims.

## SUMMARY OF THE INVENTION

The present invention is based on the idea that one laser module in each stick can be employed when using an optical processing element that generates a defined radiation pattern, for instance a row of multiple spots along the axis of the sticks and a target where the spots generated by the opposing laser module are clearly visible or detectable. With such a configuration, both sticks are still identical and no supplementary laser modules are necessary for providing an accurate alignment.

In particular, an alignment system for a light curtain monitoring a protective field comprises at least one alignment radiation source being arranged on a first support element of the light curtain and at least one alignment radiation receiver arranged on the second support element. This alignment radiation receiver provides an alignment signal indicating a correct positioning of the two support elements with respect to each other.

According to the present invention, the alignment system has at least one optical unit which has an optical processing element for generating a defined pattern from the radiation emitted by the alignment radiation source. This defined pattern can be detected by the alignment radiation receiver and the alignment signal can be generated based on the incident radiation.

The radiation receiver may be just a target surface where the radiation pattern emitted by the opposing laser module is clearly visible and can be evaluated by an operator adjusting the position of the light curtain system. However, also more sophisticated sensor systems can be used for evaluating the position of the opposing stick. According to the present invention, the optical processing element is structured to form in a planar observation region, a plurality of light points arranged in an essentially straight line from the radiation of the laser radiation source. By splitting one laser spot into various spots an alignment accuracy can be reached which normally is only achieved by using more than one laser radiation sources.

A particularly cost effective and on the other hand precisely aligned mounting of the optical unit according to the present invention can be achieved by combining the optical processing element which generates the defined radiation pattern, with at least one additional functional element, such as a lens for focussing the light curtain radiation, and/or an optical waveguide that is needed for guiding the radiation from at least one display radiation source to a surface which is visible to an observer and/or a beam expander. Such a combined optical unit has a size sufficiently large for a facilitated assembly and may even have additional alignment features for being mounted within the housing of a support element, but

on the other hand only needs a relatively small part forming the optical processing element. The optical unit may for instance be fabricated as a molded part from a plastic material or as a micromachined part made from glass, quartz, or plastic. The actual optical processing element may be fabricated from the same material or from a different material as the optical unit.

In case that the optical unit also incorporates a lens arrangement, in an advantageous way two low tolerance fabrication processes can efficiently be combined because the lenses also have to be fabricated and mounted with particularly high accuracy.

Because the optical processing element is incorporated into the optical unit in the frame of a high-precision fabrication step as it is well-established in micro machining technology, its position with regard to the optical waveguides or any other alignment features can be performed accurately and with small tolerances. The position of the optical unit with regard to the support element of the light curtain, on the other hand, is facilitated because the optical unit is large enough to be mounted in a particularly easy way.

According to the present invention, the optical processing element comprises a micro-structured Diffractive Optical Element (DOE), an optical grating structure and/or a prismatic structure for generating a defined pattern from the radiation emitted by the alignment radiation source.

DOEs utilize surfaces with a complex micro structure for a particular optical function. A micro-structured surface relief profile has two or more surface levels. The surface structures are for instance etched in fused silica or other glass types, or are embossed in various polymer materials. As this is generally known, Diffractive Optical Elements work by breaking up incoming waves of light into a large number of waves which re-combine to form completely new waves. They can be fabricated in a wide range of materials, such as aluminium, silicon, silica, plastics etc., providing the user with high flexibility and selecting the material for a particular application.

According to the present invention, a micro-structured DOE is used for generating a defined pattern of light from one single radiation source.

According to an advantageous embodiment, a plurality of light points is generated which are arranged in an essentially straight line. The straight line of light points can be used for evaluating whether the light curtain support elements are correctly aligned with respect to each other.

However, also any other shape of radiation pattern may be used for performing the alignment. For instance, also concentric circles or parallel lines may be generated from one radiation source.

According to the present invention, the light points have different intensity, the central point having a higher intensity compared to the remaining points for facilitating horizontal and vertical alignment of the support elements. However, uniform intensity can also be chosen.

Although DOEs have several significant advantages over conventional refractive optical elements, gratings or prismatic structures may of course also be used in the optical unit according to the present invention.

According to the present invention, the additional optical functional element may also comprise a beam expansion unit for adapting a cross sectional shape of a beam emitted by the alignment radiation source to the dimension of an active area of the optical processing element. In particular, when using a prismatic structure in the optical processing element, a certain size of the optical processing element cannot be undercut. Consequently, a certain minimal radiation beam diameter is required to illuminate all parts of the structure. Therefore,

according to an advantageous embodiment of the present invention, a beam expansion unit is integrated in the optical unit so that the radiation beam, in most cases a laser beam, has a sufficiently large diameter. As a beam expansion unit, firstly, well-established techniques for providing laser expanders can be exploited.

For instance, a lens system according to a Kepler or a Galileo beam expander configuration can be integrated into the optical unit. As this is generally known, in general laser applications, two basic ways of implementing beam expansion systems are known, firstly the Kepler arrangement consisting of two positive lenses or groups of lenses, and secondly, the Galileo configuration consisting of a negative and a positive subsystem. Due to the reduced installation length, the Galileo arrangement will, in most cases, be preferred for the present invention.

Furthermore, also a cylindrical lens structure preferably formed as one integral part from glass or plastic material can be used as a beam expansion unit. The advantage of such a beam expansion unit can be seen in a particularly easy fabrication and a space-saving shape.

As an alternative to the lens-based beam expansion unit, also a birefringent element can be used for expanding the radiation beam to be large enough for interacting with the complete optical processing element area. The advantage of using a birefringent material can be seen in the fact, that a beam expander unit based thereon is much easier to be fabricated than a double lens system.

In order to enhance the accuracy of the alignment of the optical axis of the alignment radiation source, the optical unit itself may comprise a means for aligning the position of the laser with respect to the optical unit and thus to the optical processing element. These alignment means may be formed, for instance, by a recess that interacts with passing of the alignment radiation source for accurately positioning same within the optical unit. For instance, an alignment shoulder or one or more alignment ribs can be provided in this recess. Providing a shoulder which extends across to the longitudinal axis of the alignment radiation source has the advantage that a much higher accuracy can be achieved.

According to the present invention, the optical processing element comprises a prismatic structure having a plurality of angled surfaces and a uniform base surface opposite to these angle surfaces. Such a structure may easily be produced and has the advantage of generating the desired radiation pattern in a very flexible and accurate way. In particular, by using different sizes of the particular prismatic areas, spots of differing brightness can be generated. The plurality of different prisms are all fabricated with one molding tool, if a molding technique is used. By partitioning the tool correspondingly, sharp edges can be achieved for the prismatic structure. Furthermore, by providing the base surface with an orientation regarding the optical axis of the incident alignment radiation beam so that it includes an angle different from 90° with the optical axis, the overall thickness of the optical processing element can be kept much more uniform, thus facilitating the molding process.

According to the present invention, a light curtain for monitoring a protective field comprises a first support element and a second support element, wherein the protective field is covered by radiation transmitted between these support elements and an alignment system according to the present invention. By designing each support element essentially identical and distinguishing between the function of the support elements only via different plug-in elements as this is known from EP 11162263.5, a particularly cost-effective fabrication of the light curtain can be achieved. For performing

5

the alignment, an operator may either evaluate the alignment radiation pattern on a particular surface of the opposing support element, or optoelectronic detectors may be provided for measuring the incident radiation pattern and for generating an electrically processible output signal.

These and other objects, advantages and aspects of the invention will become apparent from the following description. The particular objects and advantages described herein may apply to only some embodiments falling within the claims and thus do not define the scope of the invention. In the description, reference is made to the accompanying drawings which form a part hereof, and in which there is shown a preferred embodiment of the invention. Such embodiment does not necessarily represent the full scope of the invention and reference is made, therefore, to the claims herein for interpreting the scope of the invention.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a perspective view of an optical unit according to a first advantageous embodiment;

FIG. 2 shows a side view of the optical unit of FIG. 1;

FIG. 3 shows another side view of the optical unit of FIG. 1;

FIG. 4 shows a top view of the optical unit according to FIG. 1;

FIG. 5 shows a sectional view of the optical unit according to FIG. 1;

FIG. 6 shows another sectional view of the optical unit according to FIG. 1;

FIG. 7 shows an example of a radiation pattern generated by the optical processing element according to the present invention;

FIG. 8 shows an alignment of two short support elements with respect to each other;

FIG. 9 shows the alignment of two longer support elements;

FIG. 10 illustrates the allowable rotation for the short light curtain support element;

FIG. 11 shows the allowable rotation for longer light curtains;

FIG. 12 illustrates a part of a phase grating of a DOE;

FIG. 13 shows the distribution of light in the far field for the grating of FIG. 12;

FIG. 14 shows a periodic grating;

FIG. 15 shows the energy distribution in the far field generated by the grating of FIG. 14;

FIG. 16 shows a prismatic structure;

FIG. 17 shows the light distribution generated by the prismatic structure of FIG. 16;

FIG. 18 shows the housing of a support element according to the present invention;

FIG. 19 shows a perspective view of an optical unit according to a second advantageous embodiment;

FIG. 20 shows a side view of the optical unit of FIG. 19;

FIG. 21 shows a sectional view of the optical unit according to FIG. 19

FIG. 22 shows a top view of the optical unit according to FIG. 19;

FIG. 23 shows another sectional view of the optical unit according to FIG. 19;

FIG. 24 shows another sectional view of the optical unit of FIG. 19;

FIG. 25 shows a schematic representation of an intermediate laser beam shaping unit based on a cylindrical lens structure;

6

FIG. 26 shows a schematic representation of an intermediate laser beam shaping unit based on a birefringence material;

FIG. 27 shows a perspective view of a laser radiation emitting unit according to a first advantageous embodiment;

FIG. 28 shows a cut view of the laser radiation emitting device according to FIG. 27 when mounted in an optical unit according to the present invention;

FIG. 29 shows a perspective view of a laser radiation emitting unit according to a second advantageous embodiment;

FIG. 30 shows a cut view of the laser radiation emitting device according to FIG. 29 when mounted in an optical unit according to the present invention;

FIG. 31 shows a schematic cross-sectional view of a further prismatic structure to explain its fabrication;

FIG. 32 shows a schematic cross-section of the prismatic structure of FIG. 16;

FIG. 33 shows a schematic cross-section of a prismatic structure with a more uniform thickness.

#### DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 1, an optical unit according to the present invention is explained in more detail.

The optical unit **100** is designed to be mounted within a support element of a light curtain monitoring a protective field. The optical unit **100** is combining several optical functions as one integral part: Firstly, it accommodates an optical processing element **102** for generating a defined radiation pattern from the radiation which is emitted by an alignment radiation source (not shown in the figure). The optical processing element **102** may for instance comprise a micro-structured Diffractive Optical Element (DOE) which transforms the radiation emitted by a radiation source, such as a laser diode, into a pattern that can be used advantageously for aligning a support element to which the optical unit **100** is connected with respect to a second support element of a light curtain arranged in some distance thereto.

For a person skilled in the art, it is however clear that the optical unit **100** according to the present invention may advantageously be used also for other alignment tasks which utilize optical radiation for the actual alignment.

The optical processing element **102** may form a row of light dots, an array of light dots, a plurality of lines, concentric circles or square structures or any other suitable form from the incident laser beam which can be used for an alignment. In the following, only the example of forming a plurality of light points which are aligned in a straight line, will be explained in more detail, because such a linear pattern is an advantageous means for detecting a misalignment of two light curtain support elements with respect to each other.

According to the present invention, the optical processing element **102** is embedded integrally within the main body **104** of the optical unit **100**. Such a construction can either be achieved by forming the optical processing element **102** directly from the same material as the main body **104** or by separately manufacturing the optical processing element **102** and—for instance—overmolding same when fabricating the main body **104**.

According to the present invention, the optical unit **100** is produced from a plastic material, or from glass or quartz, either as a molded part or as a micro-machined part.

According to the present invention, as additional optical functional elements, one or more optical waveguides **106** are integrally formed with the main body **104**. The optical waveguides **106** guide radiation from at least one display

radiation source (not shown in the figures) to a surface **108** of the optical element which is visible for an observer. Such a compact construction of the optical unit **100** allows for a much more precise alignment of the optical processing element **102** with respect to a support element of a light curtain, because of the larger size and the oblong form. The position of the optically active structures of the optical processing element **102** with respect to the main body **104** of the optical unit can be adjusted during a high-precision fabrication step when producing the optical unit **100**, whereas the alignment of the optical unit **100** in a support element is done by a mechanical fit, as this will be explained later with respect to FIG. **18**.

Furthermore, the optical unit **100** additionally comprises an array of lenses **107** which will be mounted in a way that they focus incident light curtain radiation onto a receiver element and/or form an emitted radiation beam from an emitter element. In the present case, for instance a row of 18 lenses is integrally formed with the optical processing element **102** and the optical waveguides **106**. For a person skilled in the art it is of course clear that also only a lens array (even differently shaped) without the waveguides **106**, or any other required optical functional elements may be combined with the optical processing element **102** in order to enhance the mounting precision of the optical processing element **102**.

FIGS. **2** to **6** show several sectional and side views of the optical unit **100** according to FIG. **1**. Depending on the material from which the optical processing element **102** is made, same can be fabricated directly from the material from the main body **104** or can be incorporated for instance by overmolding a pre-fabricated optical chip. As already mentioned above, the optical processing element **102** may comprise a micro-structured DOE. However, also a simpler optical grating structure or a prismatic refractive structure may be chosen for forming the desired radiation pattern from the radiation emitted by an alignment radiation source, such as a laser.

The optical waveguides **106** guide the light from corresponding light sources, such as light-emitting diodes (LEDs) to the outer surface **108** where the light is visible for an observer. Here, a slightly tapered form of the optical waveguides **106** was chosen in order to generate a sufficiently large light point on the display surface **108**.

FIG. **7** schematically illustrates the functioning of the optical processing element **102** according to one particular example. It has to be mentioned that the present drawing is not to scale, in order to enhance the clarity for the following explanations.

An alignment radiation source **110**, for instance a laser module with a collimator, generates a laser beam **112**. The laser beam **112** passes through the optical processing element **102**. In the present example, this is a Diffractive Optical Element (DOE), which splits the laser beam **112** into a plurality of beams forming a straight line of dots **114** on a target surface **116**. As already mentioned, also other radiation patterns **114** than the one schematically shown in FIG. **7** can be achieved. In the present example the laser beam **112** is split into a radiation pattern **114** having a centre spot with larger intensity and a plurality of smaller light points with lower intensity. The distance between the optical processing element **102** and the target surface **116** for the present example may, for instance, be up to 18 m. The maximum angle indicated in FIG. **7**,  $\alpha_{max}$ , is around  $4.25^\circ$ , whereas the minimum angle between the central beam and the next following weaker beam,  $\alpha_{min}$ , amounts to about  $0.45^\circ$ . For a correct alignment of one stick of a light curtain, where the laser module and DOE is mounted, with respect to a second stick representing the target surface, about ten light spots are

needed, so that the upper half of the beams above the central beam can be used and the lower half of FIG. **7** would not be necessary.

According to the present invention, the optical unit **100** as shown in FIGS. **2** to **6** forms part of an alignment system that is used for aligning two sticks of a light curtain with respect to each other. FIG. **8** shows the alignment of a first light curtain stick **118** and a second light curtain stick **120**. In the example shown in FIG. **8**, only the first light curtain stick **118** has a laser radiation emitting device and optical unit according to the present invention, whereas the second light curtain stick has the function of a target surface. However, for a person skilled in the art it is clear that of course also both light curtains may be equipped with an alignment radiation source.

Furthermore, even if it might be advantageous to use the combined optical unit **100** having waveguides and an optical processing element in an integrated form, the general idea of aligning light curtain sticks with respect to each other by employing an optical processing element **102** can of course also be realized by only using a radiation source and the optical processing element, as explained with respect to FIG. **7**.

In FIG. **8** the alignment of two rather short light curtain sticks, for instance having a length of about 150 mm, is explained. It is assumed that the first light curtain stick has an alignment radiation source and optical processing elements, which generate a radiation pattern **114**, as shown in FIG. **7**.

As can be seen from FIG. **8**, in a distance of 2 m between both sticks and below, all ten light spots can be evaluated on the second light curtain stick **120**. A distance of 6.8 m and 9.5 m are the limit for still being able to use the third and second beam, respectively. The fact that at least two light points, i.e. the central beam and the first side beam are needed for an alignment, leads to the limit of a distance of 19 m using the particular radiation pattern of FIG. **7** with a minimal angle  $\alpha_{min}$  of  $0.45^\circ$  and a maximum angle of  $\alpha_{max}$  is  $4.25^\circ$ .

On the other hand, as shown in FIG. **9**, with a radiation pattern **114** as shown in FIG. **7**, all ten light spots are visible on a light curtain stick of 1.50 m in a distance from the light source of 20 m. Short light curtain systems, as the one depicted in FIG. **10**, allow for an operation distance between 10 m and 18 m and a maximum rotation of  $\pm 50^\circ$  at a distance between 2.00 m and 2.15 m without interruption of the light curtain. In a distance range between 2.15 m and 20 m, a complete rotation of the position between the two sticks is possible without interrupting the light curtain.

The allowed rotation for long light curtain sticks is schematically depicted in FIG. **11**. Depending on the operating distance between the first and second light curtain stick, and assuming an effective aperture angle of about  $2^\circ$ , the laser spot tolerances for correct operation are given on the right-hand side of FIG. **11**, whereas the maximum possible rotation angle is summarized on the left-hand part of FIG. **11**. The maximum possible rotation occurs at 18 m and amounts to  $\pm 45^\circ$ .

In summary, the alignment system using a radiation pattern, as shown in FIG. **7**, at a two meters distance and a length of the light curtain sticks of 1500 mm allows a rotation of  $5^\circ$  of the stick. With a 14 mm deviation of the topmost laser point or a 131 mm deviation of the topmost end of the stick, the line of light points can still easily be seen. Generally, it could be shown that longer sticks at short distances are easier to align (refer to FIG. **9**).

From a more abstract point of view, the optical processing unit **102** should be designed in a way to generate a desired light pattern from a given radiation beam. In the above-explained example, this should be for instance a row of ten laser

radiation points having a distance of about  $0.4^\circ$ . As already mentioned, there exist several possibilities of transforming the light from one radiation source into such a pattern. The first possibility is the use of a computer-generated Diffractive Optical Element (DOE). FIG. 12 depicts an example of a phase grating of such a DOE. Such a DOE has the advantage that the desired radiation pattern can be generated with the highest flexibility and accuracy. However, the fabrication expenditure is rather high and—as a binary DOE is not sufficient to generate this radiation pattern—a four-step DOE, as shown in FIG. 12, has to be designed.

FIG. 13 shows the light distribution, which is generated in the far field. In particular, the squared amplitude is shown as a function of the position.

Alternatively, an optical grating of a periodic form can be used as shown in FIG. 14. This structure is also based on the principle of light diffraction, but is much easier to fabricate. However, a periodic diffraction grating as shown in FIG. 14 has the disadvantage that the degree of the energy distribution can be influenced to a much smaller extent. FIG. 15 shows the energy distribution in the far field, which can be generated by using the periodic grating of FIG. 14 for an optical processing element 102 according to the present invention.

Finally, not only diffraction, but also refraction can be used for generating a radiation pattern suitable for an alignment of two light curtain sticks with respect to each other. FIG. 16 shows such a prismatic structure and FIG. 17 depict the belonging light distribution in a distance of 3 m. A linear structure of prisms with steadily changing angles, as shown in FIG. 16, also has the advantage of the comparatively simple fabrication. A disadvantage of using a prismatic structure can be seen in the fact that the laser points are deformed by some extent and that when using a small laser cross section, mounting tolerances have therefore to be taken into account.

FIG. 18 shows an example of a light curtain support element 122, which on the one hand is formed to accommodate the optical elements for forming the light curtain and, on the other hand, has a recess 124 for mounting the optical unit 100' (as shown in the following FIGS. 19 to 24) according to the present invention.

When using the present invention in the frame of a modular transceiver bar according to European patent application EP 11 162263.5, both support elements of the first and the second light curtain stick can be formed identically, each having the recess 124. The functionality of the respective light curtain stick is then defined by a plug-in module (not shown in the figure). In this case, the alignment radiation source which is housed in the opening 126, can either be left inactive for one of the light curtain sticks or it can be used in both directions.

An alternative embodiment of an optical unit 100' is shown in FIGS. 19 to 24. The main difference to the first example is the omission of the lenses and the reduction of the material in the area of the main body 104'. In contrast to the optical unit 100 shown in FIGS. 1 to 6, this embodiment has longer optical waveguides 106', and firstly allows a fabrication which adds the optical waveguides from a different material as the main body 104' and furthermore, needs less material that might be costly, if it is for instance fused silica or another micro-machined part.

In summary, the present invention firstly has the advantage that by using a Diffractive Optical Element (DOE) a laser beam is split into various spots of different intensity so that a central spot is easily visible, thus facilitating a horizontal alignment, whereas all others are arranged in one exact row, thus facilitating the vertical alignment. This alignment system allows for a much cheaper alignment of the two sticks of a safety light curtain, because the building of two identical

sticks is possible and only one laser module for each stick is required. A direct comparison shows that even when using as the optical processing element a computer-generated DOE, same is cheaper than providing an additional laser module.

Furthermore, when combining the optical processing element with one or more additional optical functional elements, such as lenses or optical waveguides to form optical units according to the present invention, an accurate positioning of the element within the module is possible, thus providing the spots in the required tolerance. The optical unit is a longer element than only a DOE chip, but is less costly than providing a larger DOE.

A further aspect of the present invention will now be explained with reference to FIGS. 25 and 26. For most of the optical processing units 102 shown in the previous figures, a laser beam diameter is needed which exceeds the dimensions that can be reached by conventional alignment radiation sources 110. Consequently, for widening the laser beam, a beam expanding unit 128 may be provided as shown in FIG. 25. The initial laser beam 112 is expanded to an expanded laser beam 113 having an elliptical cross-section which is larger than the circular diameter of the initial laser beam 112.

It could be shown that by providing a laser beam with an elliptic or line shaped diameter which has a longitudinal axis that reaches both ends of the optical processing element, a sufficiently split radiation pattern can be generated. Such a widening of the circular beam is necessary for a combination of the optical processing element 102 with standard laser modules because for proper functioning of the optical processing element, a sufficient number of the different structures present on the optical processing element 102 have to be illuminated. For instance, in the case of a prismatic structure, each of the individual prisms has to be illuminated.

Downsizing the geometric dimensions of these prisms is normally not an option because there are usually limits to their miniaturisation due to fabrication restrictions. However, it is not necessary to use a laser beam with a circular cross-section; a widening to an elliptic cross-section is sufficient. The advantage of using standard laser modules with small round beam diameters together with a beam expanding unit 128 can further be seen in the fact that the orientation of the laser module 110 with respect to its rotational angle around the beam axis does not have to be adjusted during assembly. The orientation of the elliptic cross-section of the laser beam arriving at the optical processing element 102 is aligned by the orientation of the beam expanding unit 128 which can be fabricated together with the optical processing element allowing for low tolerances. The expanded laser beam generates a homogeneous illumination of all parts of the optical processing element 102, thus ensuring proper generation of the radiation pattern.

For expanding the laser beam, all known expander principles may be used. For instance, a Kepler or Galileo arrangement in a miniaturised microstructured form can be implemented.

The beam expanding unit 128 may also comprise a birefringent material, as shown in FIG. 26.

As this is generally known, crystals are classified as being either isotropic or anisotropic depending upon their optical behaviour. Anisotropic crystals have crystallographically distinct axes and interact with light in a manner that is dependent upon the orientation of the crystalline lattice with respect to the incident light. When light enters along the optical axis of an anisotropic crystal, it acts in a manner similar to the interaction with isotropic crystals and passes through at one single velocity. However, when light enters along a non-equivalent axis, it is refracted into two rays; each polarised with the

11

vibration directions or vented at right-angles to one another and travelling at different velocities. This phenomenon is termed “double-” or “bi-refraction” and is seen to a greater or lesser degree in all anisotropic crystals. When anisotropic crystals refract light, the resulting rays are polarised and travel at different velocities. The ray which travels with the same velocity in every direction through the crystal is termed the “ordinary ray” as shown in FIG. 26.

The other ray travels with a velocity that is dependent upon the propagation direction within the crystal. This light ray is termed the “extraordinary ray”. The distance of separation between the ordinary and extraordinary ray increases with increasing crystal thickness 130. In order to ensure that there will be no gap between the ordinary beam and the extraordinary beam, a well-defined maximum thickness of the beam expanding unit 128 will have to be maintained. By appropriately choosing the material, orientation and thickness of the birefringent beam expanding unit 128, an enlarged diameter of the laser beam can be achieved by superposing the ordinary beam 132 and the extraordinary beam 134.

Proper functioning of the optical axis of the radiation source 110 with respect to the optical processing element 102 is important. In particular, the laser beam should have a well-defined angle of incidence with respect to the surface of the optical processing element, usually 90°. Due to the small dimensions of the radiation sources usable with the present invention, alignment features should be provided at the support elements which hold the radiation source 110 and the optical processing element 102.

An advantageous possibility of certain alignment will be explained with respect to FIGS. 27 and 28. According to this embodiment, the laser module 110 has a cylindrical housing 136 with a circumferential step formed shoulder 138. As can be seen from FIG. 28, the shoulder 138 interacts with the stop 140 which is provided in a mounting recess 142 of the optical unit 100. The stop 140 can be fabricated with high accuracy in regard to the position of the optical processing element 102. Consequently, the optical axis of the radiation source 110 can be efficiently aligned with the optical processing element 102. The tolerances can be kept small because surfaces being perpendicular to the optical axis act as a reference. By additionally providing potholes in the recess in the optical unit 100, glue can be deposited which will fix the laser module 110 in the optical unit 100 permanently.

A different shape of a laser module is shown in FIGS. 29 and 30. According to this embodiment, the radiation source 110' has an elongated cylindrical housing which does not have any protrusions thereon. In this case, as may be derived from FIG. 30, the outer longitudinal surface of the cylinder is used for aligning the optical axis of the laser module 110' with respect to the optical processing element 102. For this alignment, the recess 142 wherein the laser module 110' is mounted, has protruding guiding ribs for aligning and centring the laser module 110'. Again, glue can be used for fixing the laser module 110' within the recess 142.

When additionally taking into account FIG. 18, it is clear for a person skilled in the art that the recess 142 of FIGS. 27 and 28 or 29 and 30, respectively, may also at least partly be formed in the light curtain support element 122 where the optical unit 100 is mounted.

With respect to FIGS. 16 and 17, a first advantageous prismatic structure for implementing an optical processing element 102 according to the present invention has been explained. However, there are several further possibilities of designing such a prismatic optical processing element 102. A further advantageous embodiment is shown in FIG. 31. The prism structure of FIG. 16 has a regular order of the prisms;

12

each prism region having the same width of 0.08 to 0.36 mm each, depending on tooling options and laser beam diameters. This structure has to be repeated at the borders because of the laser beam position tolerances and the width of each prism should be adjusted to the individual beam brightness requirements.

Referring now to FIG. 31, the prismatic structure has a total width  $w$  of less than 2 mm. In order to generate all split laser beams except those which are redundant, the laser beam must have a minimum diameter of about two thirds of the total width.

FIG. 31 also schematically illustrates a fabrication tool for molding the optical processing element 102 of this figure. In order to avoid that in convex regions of the optical processing element where two surfaces form an angle of less than 180°, a rounded profile is produced instead of a sharp linear boundary, a tool for forming this optical processing element is separated into several pieces. Whenever the tool would have a concave angle, the same is partitioned in order to ensure sharp edges of the optical processing element.

Still another embodiment of a prismatic optical processing element 102 is shown in FIGS. 32 and 33. The problem of fabricating the prismatic structure according to FIG. 31 or 32 (which essentially corresponds to the one shown in FIG. 16) can be seen in the fact that the structure is thicker at one end than at the other. Such a difference in material thickness impedes molding of the structure and for facilitating the molding process according to a further embodiment, the structure as shown in FIG. 33 can be used. Here, the base surface 146 opposing to the angled surfaces 144 is also angled with respect to the optical axis of the incident laser beam.

This modification does not have any impact on the generated radiation pattern, but facilitates the molding process due to an approximately constant thickness of the optical processing element 102.

For an alignment with respect to the optical axis, either a respective angled surface at the main body 104 of the optical unit 100 can be provided, or processing element 102 can be provided with projections at the peripheral parts which provide a 90° bearing surface for being supported by the seating of the main body 104 of the optical unit 100.

Generally, an optical processing element 102 according to the present invention has the advantage that the minimum structural size of the tool is larger than of one single prism. This overcomes the problem that small prismatic structures would be difficult to integrate into a molding tool. The edges at the transition from one prism to the next have to be very sharp in order to achieve a good contrast of the individual spots. These sharp edges can be achieved according to the present invention by appropriately partitioning a molding tool. Furthermore, by combining different sizes of prisms, spots having a different brightness can be generated. According to the present invention, the different prisms are arranged so that some peaks of the tool are grouped together, wherein these groups can be built with one single part of the tool in order to keep the peaks sharp. The dimensions of such a group are still much larger than only one single prism and these groups are separated according to the peaks of the prism representing indentations of the tool. Different brightness of the spots can require very narrow prisms which may be fabricated in a reproducible way with low tolerances by combining them with larger prisms.

Finally, it should be mentioned that the use of the terms “a” and “an” and “the” and similar referents in the context of describing the invention (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or

13

clearly contradicted by context. The terms “comprising,” “having,” “including,” and “containing” are to be construed as open-ended terms (i.e., meaning “including, but not limited to,”) unless otherwise noted. Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein.

All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (e.g., “such as”) provided herein, is intended merely to better illuminate the invention and does not pose a limitation on the scope of the invention unless otherwise claimed. No language in the specification should be construed as indicating any non-claimed element as essential to the practice of the invention.

Exemplary embodiments are described herein. Variations of those embodiments may become apparent to those of ordinary skill in the art upon reading the foregoing description. The inventor(s) expect skilled artisans to employ such variations as appropriate, and the inventor(s) intend for the invention to be practiced otherwise than as specifically described herein. Accordingly, this invention includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the invention unless otherwise indicated herein or otherwise clearly contradicted by context.

Certain terminology is used herein for purposes of reference only, and thus is not intended to be limiting. For example, terms such as “upper,” “lower,” “above,” and “below” refer to directions in the drawings to which reference is made. Terms such as “front,” “back,” “rear,” “bottom,” “side,” “left” and “right” describe the orientation of portions of the component within a consistent but arbitrary frame of reference which is made clear by reference to the text and the associated drawings describing the component under discussion. Such terminology may include the words specifically mentioned above, derivatives thereof, and words of similar import. Similarly, the terms “first,” “second” and other such numerical terms referring to structures do not imply a sequence or order unless clearly indicated by the context.

When introducing elements or features of the present disclosure and the exemplary embodiments, the articles “a,” “an,” “the” and “said” are intended to mean that there are one or more of such elements or features. The terms “comprising,” “including” and “having” are intended to be inclusive and mean that there may be additional elements or features other than those specifically noted. It is further to be understood that the method steps, processes, and operations described herein are not to be construed as necessarily requiring their performance in the particular order discussed or illustrated, unless specifically identified as an order of performance. It is also to be understood that additional or alternative steps may be employed.

It is specifically intended that the present invention not be limited to the embodiments and illustrations contained herein and the claims should be understood to include modified forms of those embodiments including portions of the embodiments and combinations of elements of different embodiments as coming within the scope of the following claims. All of the publications described herein including patents and non-patent publications are hereby incorporated herein by reference in their entireties.

14

What is claimed is:

1. An optical unit for an alignment system of a light curtain monitoring a protective field, the optical unit comprising:
  - an optical processing element configured to generate a defined radiation pattern from a radiation emitted by an alignment radiation source of the alignment system, and at least one additional optical functional element being formed integrally with the optical processing element, wherein the optical functional element comprises a beam expansion unit for adapting a cross sectional shape of a beam emitted by the alignment radiation source to a dimension of an active area of the optical processing element.
2. The optical unit of claim 1, wherein the beam expansion unit comprises a lens system according to at least one of a Kepler or a Galileo beam expander configuration, a birefringent element, and a cylindrical lens element.
3. The optical unit of claim 1, wherein the optical unit comprises at least one of an optical wave guide for guiding radiation from at least one display radiation source to a surface of the optical unit which is visible to an observer, and a lens for focusing radiation forming the light curtain.
4. The optical unit of claim 1, wherein the optical processing element is structured to form, in a planar observation region, a plurality of light points arranged in an essentially straight line from the radiation of a laser radiation source.
5. The optical unit according to claim 1, wherein the optical processing element is structured to form, in a planar observation region, a plurality of light points having differing intensities, wherein a central point has a higher intensity compared to remaining points.
6. The optical unit according to claim 1, wherein the optical processing element comprises at least one of a micro-structured Diffractive Optical Element (DOE), an optical grating structure, and a prismatic structure.
7. The optical unit according to claim 1, further comprising a mounting recess for mounting the alignment radiation source, the mounting recess having at least one alignment shoulder extending across a longitudinal axis of the recess for aligning the alignment radiation source with respect to its optical axis.
8. The optical unit of claim 1, further comprising a mounting recess for mounting the alignment radiation source, the mounting recess having at least one alignment rib extending along a longitudinal axis of the recess for aligning the alignment radiation source with respect to its optical axis.
9. The optical unit of claim 1, wherein the optical unit is fabricated as at least one of an integral molded part from a plastic material, or as a micromachined part from at least one of a glass, quartz, or plastic.
10. The optical unit of claim 1, wherein a plurality of waveguide elements are formed at the optical unit, each waveguide being formed to image light from a status indicating LED onto a display region of the optical unit.
11. The optical unit of claim 1, wherein a plurality of lenses are formed at the optical unit, each lens being formed to focus radiation transmitted to cover the protective field.
12. The optical unit of claim 1, wherein the optical processing element comprises a prismatic structure having a plurality of angled surfaces and a uniform base surface opposite to these angled surfaces.
13. The optical unit of claim 12, wherein the base surface is oriented across an optical axis of an incident alignment radiation or includes angle different from 90° with the optical axis.
14. An alignment system for a light curtain monitoring a protective field, the light curtain comprising:

**15**

a first support element and a second support element, wherein the protective field is covered by radiation transmitted between the first and second support elements,

wherein the alignment system comprises at least one alignment radiation source being arranged on the first support element and at least one alignment radiation receiver arranged on the second support element for receiving the alignment radiation and for providing an alignment signal indicating a correct positioning of the two support elements with respect to each other,

the alignment system further comprising at least one optical unit having an optical processing element configured to generate a defined pattern from the alignment radiation emitted by the at least one alignment radiation source, and

at least one additional optical functional element being formed integrally with the optical processing element, wherein the optical functional element comprises a beam expansion unit for adapting a cross sectional shape of a beam emitted by the alignment radiation source to a dimension of an active area of the optical processing element.

**15.** The alignment system according to claim **14**, wherein the alignment radiation receiver comprises a target surface for reflecting the radiation pattern, the reflection forming the alignment signal.

**16**

**16.** A light curtain for monitoring a protective field, the light curtain comprising:

a first support element and a second support element, wherein the protective field is covered by radiation transmitted between the first and second support elements;

an alignment system for the light curtain comprising at least one alignment radiation source being arranged on the first support element and at least one alignment radiation receiver arranged on the second support element for receiving the alignment radiation and for providing an alignment signal indicating a correct positioning of the two support elements with respect to each other;

at least one optical unit having an optical processing element configured to generate a defined pattern from the alignment radiation emitted by the alignment radiation source; and

at least one additional optical functional element being formed integrally with the optical processing element, wherein the optical functional element comprises a beam expansion unit for adapting a cross sectional shape of a beam emitted by the alignment radiation source to a dimension of an active area of the optical processing element.

\* \* \* \* \*